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NOTES ON FROST.

BY

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF THE WEATHER BUREAU,
Washington, D. C., August 2, 1910.

SIR: I have the honor to recommend that the manuscript herewith be published as a revised edition of Farmers' Bulletin No. 104.

In compliance with directions contained in your letter of March 29, 1899, a paper on the subject of frost, prepared by Prof. E. B. Garriott, Weather Bureau, was submitted and published as Farmers' Bulletin No. 104. This bulletin furnished valuable information regarding methods of protection from frost. Methods advocated in previous publications were mainly the results of experiments conducted in California orchards. Bulletin No. 104 was designed to be of value in all sections of the country rather than in restricted districts.

As the California experiments quoted were perhaps the most thorough ever made in this country, a description of the methods employed and the results obtained is reprinted in brief in this paper, together with results of similar experiments made in the citrus-fruit and truck-growing districts of the Gulf States, where varying climatic conditions have been found to produce somewhat different results. Additional information personally acquired by Professor Garriott during a visit to Florida in the winter of 1906–7, and certain climatic data, also form features of this paper in its revised form.

The development of orchard heaters and other devices now successfully used in saving crops from injury by frost necessitates a new issue of this bulletin. Owing to the death of Professor Garriott, the revision has been undertaken at my direction by Professor McAdie.

Your wishes that the subject be treated in a popular way and divested of all technicalities, and made applicable to all portions of the United States, have been complied with so far as the nature of the subject will permit.

Respectfully,

WILLIS L. MOORE,
Chief, Weather Bureau.

Hon. JAMES WILSON,
Secretary of Agriculture.

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HOW FROST IS FORMED.

The atmosphere of the earth always contains more or less moisture in an invisible form. When at a considerable elevation above the earth this moisture, or aqueous vapor, is condensed, clouds are formed; when the process of condensation is more active and the temperature of the air is above freezing, rain falls; and when the temperature of the air is below freezing, snow is produced. When the moisture of the air in immediate contact with the earth is condensed at temperatures above freezing, dew is formed; when at temperatures below freezing, frost is deposited. Frost is, therefore, the moisture of the air condensed at freezing temperatures upon plants and other objects near the surface of the earth.

In the process of frost formation the temperature of the air a few feet above the earth is commonly several degrees above freezing. The surfaces upon which frost is deposited must, however, possess freezing temperatures. The manner in which frost is deposited on plants and other objects is very similar to that in which the air moisture of a room is frozen and deposited upon window glass, the temperature of which has been reduced to freezing by the out-of-doors cold. In the case of the frost on the window glass the process is one that can readily be understood. Some explanation, however, is required of the formation of frost, which requires freezing temperature, when at times a temperature above freezing is registered a few feet above the surfaces upon which frost appears.

There are several processes by which the temperature of plants may be reduced below the temperature of the air which surrounds them. The most important of these processes is radiation, by means of which heat escapes from objects and passes into the surrounding air.

In the frost-forming process heat from the sun which is absorbed by the earth and by plants during the day is lost by radiation at night. During the day the earth both absorbs and reflects the heat received from the rays of the sun, and the lower stratum of air is warmed by this reflected heat. During the night when no direct heat is received from the sun's rays the lower air stratum receives no reflected heat,

and, at the same time, heat which has been absorbed by the earth is radiated, or, in other words, it rises through the overlying air, though not necessarily and entirely as sensible heat; that is, heat perceptible to the senses. In the frost-forming process there is another very important factor in the production of cold; that is, the evaporation of moisture from the earth and from plants. The nature and composition of frost require that the air in immediate contact with the surfaces upon which frost forms shall contain moisture. This is moisture that has been stored in the earth in visible form, i. e., in the form of water, and which has escaped from the earth, not as visible moisture, but by the process of evaporation and in the form of aqueous vapor. Some part of the heat stored by the earth during the day is, therefore, lost in evaporating the moisture contained in plants and in the earth. The heat expended in this process is not sensible, but latent. Heat is rendered latent when it is used to boil away water, and it becomes sensible or liberated heat when the water vapor again condenses into water. It appears, therefore, that the temperature of surfaces upon which frost forms, and of the air in immediate contact with them, is lowered by the evaporation of moisture from the surfaces. The influence of the process does not extend to air a few feet above the ground.

Another method by which plants lose their heat is by convection, by means of which they are chilled by contact with colder air. This process, while important in the presence of freezing air temperatures, can scarcely be considered a factor in the formation of frost proper, which is usually accomplished when temperature observations show the air to be above freezing.

Air arranges itself according to its density or weight. Air in immediate contact with the earth becomes heavier as its temperature is lowered by the radiation of heat and settles in depressions or valleys and over lowlands, causing, at times, frost in low-lying districts, while neighboring higher grounds escape the visitations.

NOTE.—A given quantity of heat absorbed by several substances of different specific heat will produce a different temperature in each; the lower the specific heat of the substance the higher will be its temperature; and besides, different substances have different coefficients of absorption and of reflection. Therefore under the same insolation rocks, clay, vegetation, and other substances come to temperatures that often differ by many degrees.

The air next to earth largely partakes of the temperature of the surface, and in consequence, when the sky is clear, so that incoming and outgoing radiations may progress freely, and the air is but little disturbed by wind, wide variations in the temperature of the thin stratum of lower air may occur over adjacent plots of ground of *precisely* the same elevation but different covering.—Moore's Descriptive Meteorology, page 108.

SEASONS OF FROST.

Generally speaking, agricultural products in some part of the United States are menaced by frost from the time nature begins to extend her mantle of green from the citrus regions of the South toward the grain fields of the North until the verdured area contracts southward before the first winds of winter; from the hour that seeds germinate and buds blossom until crops are gathered; from early spring until late fall. As a rule, the critical periods are during the early growth of plants and when the fruit is in the bloom, and again when crops are maturing. In the first instance vegetation is threatened by the frosts of early spring, and in the latter by the frosts of autumn.

Considering the several agricultural sections in greater detail we find that damaging frost is likely to occur in the north half of the Florida peninsula, the region immediately bordering the coast of the Gulf of Mexico, and in the interior of California from the latter part of October until the early part of April, and in the North Pacific Coast States as early as the middle of October and as late as the last week of April. From December until early in March the frost limit and even the line of freezing temperature may, at long intervals, be extended southward over central and southern Florida. The period of damaging frosts in the interior of the South Atlantic and Gulf States extends from November to April. From October to April the region in which agricultural products are subject to damage by frost is extended to the southern lake region, over the Upper Mississippi and Lower Missouri valleys, Kansas, and Nebraska, and from September to May frost visitations are usually confined to the extreme Upper Mississippi, Upper Missouri, and Red River of the North valleys, and the Rocky Mountain and plateau regions from central New Mexico and the Texas Panhandle northward. (See figs. 1 and 2.)

The occurrence of summer frosts in mountain regions and in extreme northern districts of the country is common. The following are notable instances of summer frosts in agricultural districts:

August 22 to 24, 1890, a frost-bearing cool wave advanced from the Dakotas over the lake region and the interior, or mountain districts, of the middle Atlantic States.

August 28 to 31, 1892, a cool wave advanced from the Rocky Mountain and plateau regions, with frost from New Mexico to the Dakotas, Iowa, Minnesota, northern Wisconsin, and northern Michigan.

August 8, 1904, frost damaged vegetation in low-lying lands in the States of the upper lake region.

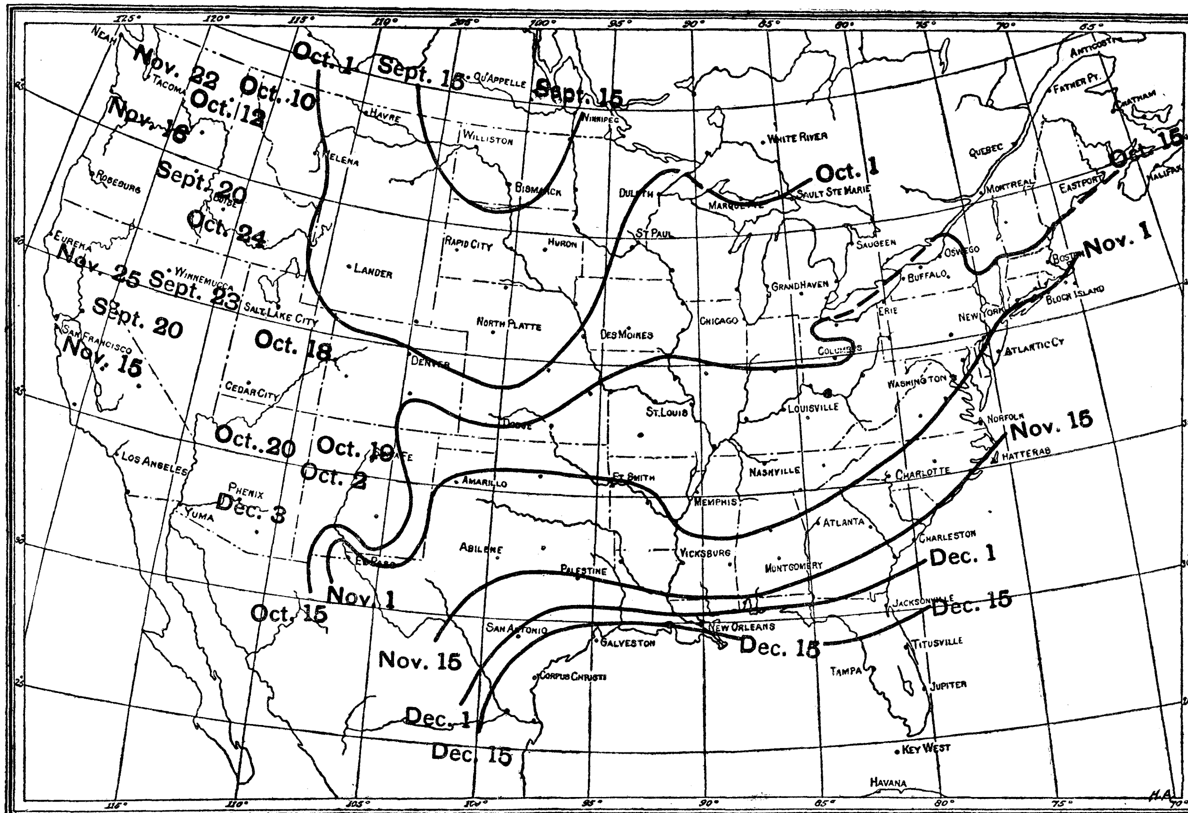

FIG. 1.—Chart showing average date of first killing frost in autumn.

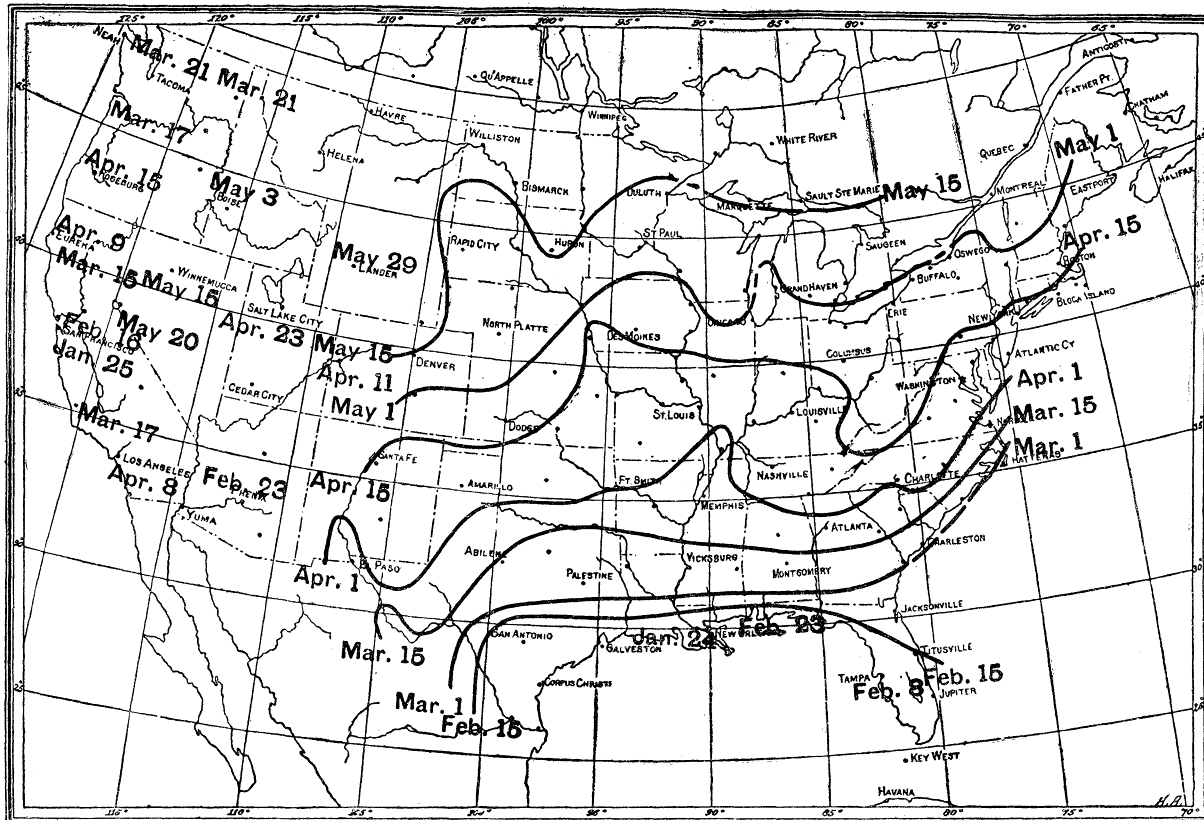

FIG. 2.—Chart showing average date of last killing frost in spring.

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Bulletin P, of the Weather Bureau, gives a chronological statement of the more important cold periods that have been experienced in the United States, and contains charts that present conditions that preceded and attended the principal cold waves and frosts of the fifteen years from 1888 to 1902.

WHEN TO EXPECT FROST.

As the conditions which produce damaging frost are subject to modifications which are as numerous as the kinds of crops raised, and as varied as local topography, local climate, and local soil conditions in the various sections of the United States, the writer in attempting to treat briefly a subject which is so diversified in its aspects is confronted with many difficulties. Suffice it to say that with other atmospheric conditions favorable for its occurrence frost may, as a rule, be expected when temperature, as reported by stations of the Weather Bureau, falls to a point 8° to 10° above the freezing point. As previously stated, the surfaces upon which frost is deposited must be at or below freezing temperature, although the temperature of the air a few feet above may be several degrees above freezing. It is the temperature of the air, in some instances many feet above the ground, that is given by the Weather Bureau observations. Another atmospheric condition favorable for the occurrence of frost is a clear, cloudless, and comparatively calm night. Clouds retard radiation or loss of heat from plants and act as a screen in preventing the heat collected from the sun's rays during the day from escaping into the upper air. When clouds are not present and a withdrawal of the sun's rays causes a rapid cooling of the air at moderate elevations, the warmer air which collects near the surface of the earth during the day rises, and the cooler upper air, owing to its greater density or weight, settles to the earth. It will be noted that clouds not only prevent the escape of the warm air in immediate contact with the earth, but also blanket, as it were, the upper part of the lower air stratum. Calm or comparatively still air is a condition which favors the formation of frost. On windy nights the air is disturbed and is not permitted to arrange itself in layers according to its density, with the densest and coldest air near the surface of the earth; it is kept mixed up by the wind.

A very interesting fact, which illustrates the manner in which cold air settles by its greater weight to the surface of the earth and allows the warmer air to assume higher levels, causing frost in low grounds and granting to the higher grounds a comparative immunity from frost, is set forth in the following article, by Prof. Cleveland Abbe, in the Monthly Weather Review for December, 1893, entitled Thermal Belts, Frostless Belts, or Verdant Zones:

These are local names given to certain regions on mountain sides within which nocturnal frost rarely or never occurs in the springtime, although freezing tempera-

tures occur in the winter time. Consequently tender vegetation flourishes with remarkable vigor in these regions. The following are the only references to thermal belts in the United States at present known to the editor, but as such regions are specially important to the horticulturist and agriculturist it is hoped that the correspondents of the Weather Bureau will bring these thermal belts to notice wherever they occur in order that their meteorological peculiarities may be better understood.

In the Agricultural Report of the Patent Office for 1861 Mr. Silas McDowell, of Franklin, Macon County, N. C., describes the verdant zone in that county in the valley of the Little Tennessee River. It occupies the region between 300 and 700 feet above the valley of the river, which latter is about 2,000 feet above sea level. On tracing this zone up among the smaller tributaries of the Tennessee River he found that in the higher valleys, where the bottom land is about 3,900 feet above sea level, the verdant zone lies between 4,000 and 4,100 feet. Within this zone frost never injures the vegetation, and the most tender grapes never fail to produce abundant crops.

Prof. J. W. Chickering, jr., in the bulletin of the Philosophical Society of Washington, March, 1883, and in the American Meteorological Journal, volume 1, describes the following thermal belt: "In Polk County, N. C., along the eastern slope of the Tryon Mountain range, in latitude north 35, the thermal belt begins at the base of the mountain, at an elevation of 1,200 feet above the sea, and extends up 2,200 feet, being most perfect at about 1,500 feet. It is about 8 miles long, and is distinguished by magnificent flora, such as would be characteristic of a point 3 degrees south of the actual latitude."

Prof. John Leconte, of Berkeley, Cal., in Science, volume 1, page 278, states that at Flat Rock, near Hendersonville, Henderson County, N. C., on the flank of the mountain spur adjacent to the valleys of the Blue Ridge, he also observed a frostless zone. The valley is about 2,200 feet above sea level, and the thermal belt is 200 to 300 feet above the valley.

In the American Meteorological Journal, volume 1, Mr. S. Alexander describes a thermal belt in which the peach tree flourishes in the southeastern portion of Michigan. He shows that the cold island discovered by Winchell in that region is really the bottom of a topographical depression into which the cold air settles. It is a long valley surrounded by a belt of elevated country from 50 to 600 feet above lakes Michigan and Huron. The valley and the isotherms trend northeast and southwest from Huron County through Sanilac, Lapeer, Oakland, Livingston, and Washtenaw to Hillsdale County. The highlands of this region are all much freer from frost than the lowlands, and all much more favorable for early vegetation. He does not state that any point is high enough to be above the thermal belt, but that, in general, two equal parallel thermal belts inclose the cold island between them.

The thermal belts of California are described in various publications of the Weather Bureau, particularly Bulletin L, "Climatology of California."

In the various numbers of the Monthly Weather Review and in the various summaries published by section directors and district editors special attention has been given to zones of little injury from frost. In nearly every section there are some specially favored localities. One example will serve to illustrate. In the Monthly Weather Review for May, 1910, Professor Howard, secretary of the Missouri state board of horticulture, calls attention to the fact that certain sections in that State, for no apparent reasons based upon

topography or isotherms, nearly always escape injury. He instances particularly the famous peach region about the town of Koshkonong, in Oregon County. Mr. George Reeder, section director, after a careful examination of climatic data, comes to the conclusion that the apparent immunity of orchards in the neighborhood under discussion from damaging temperatures in the spring is probably due to local air drainage, the cold air being drained away from the orchards. He gives tables showing that the cold air spreads out and is drained away down the southern slope of the Ozark plateau, sometimes more toward the southwestward, then toward the south, and again the flow may affect only the southeast. Mr. Reeder states:

It appears as if the cold air current had divided, one part rolling toward the White River Valley, as indicated by the temperature at Hollister, and the other part going toward the Black River Valley, as indicated by the temperature at Doniphan. Instead of the favorable peach belt, if any, extending east and west as suggested by Professor Howard, it probably extends northerly and southerly, or, in other words, it lies along the Ozark border, a narrow strip of table land having elevations ranging between 1,000 feet, on which are situated Koshkonong, Mo., and Mammoth Springs, Hardy, and La Crosse, Ark. This strip bends not far from La Crosse and thence extends northwestward above the White River Valley. The temperature on this border does not fall so low at times as does that at lower as well as higher altitudes.

The cold of April 25 and 26, 1910, that caused so much damage to the fruit crop of Missouri, was quite uniformly distributed over the section under discussion, as may be seen from the following table:

County.	Station.	Temperature.	Date.
		° F.	
McDonald	Dean	28	Apr. 26
Taney	Hollister	31	Apr. 26
Howell	Olden	27	Apr. 25
Oregon	Koshkonong	29	Apr. 25
Ripley	Doniphan	32	Apr. 25

The cold spell was accompanied by cloudy skies and rain mixed with snow, and the movement of the cold currents of air was quite different from that which takes place under a clear sky, or when there is no rain or snow. It will be observed that during cold periods, with more or less cloudiness and moisture, the temperature on the hills may fall to a lower value than the temperature in the valleys; on the other hand, had clear weather prevailed during the nights of April 25 and 26, the temperature conditions would have been reversed, the valleys probably being much colder. It is also quite clear, had the fruit in the valleys escaped winter injury it would have received no more damage from the freeze of April than was sustained in the neighborhood of Koshkonong.

Professor Abbe states in Monthly Weather Review for December, 1903:

It is generally conceded that these thermal belts depend both upon the drainage of cold air downward into the lower valleys and the freedom of radiation from the surface of the ground to the clear sky overhead. During a still night, when

frosts occur, the surface of the hillside cools by radiation, and hence cools the air in contact with it; the latter flows downward as long as its cooling by radiation and conduction exceeds its warming by compression. Inasmuch as its cooling depends on contact with a still colder soil or plant, it soon accumulates in the lowlands as a layer of cold air, which grows thicker during the night by the steady addition of the thin layer of descending air in contact with the ground on the hillsides. The warmer air, which has not yet had an opportunity to cool by contact with the ground, floats on top of the cold mass; it spreads out toward the hills, and is continuously furnishing its heat to the adjacent hillsides as fast as it comes in contact with them before it also cools and descends. The formation of the thermal belt seems to depend largely upon this gentle circulation during the night-time. The lower limit of the belt is defined by the depth of the accumulation of cold air in the confined valley and rises higher in proportion as the night is clearer and longer, and also in proportion as the valley is more or less perfectly inclosed. The upper limit of the thermal belt may depend upon the strength of the wind and the general temperature of the air. But if there be no wind, then it depends equally on the freedom of radiation to the clear sky and on the above-described circulation of air.

The facts quoted above show that frost may be expected on low grounds at times when higher grounds escape the visitations, and the lesson they teach is that early and tender crops should, so far as may be practicable, be confined to crests, hillsides, and mountain sides, and later and hardier crops to the lowlands and valleys.

Local climate, as it is influenced and regulated by the proximity of bodies of water, must be given great weight in calculations regarding frost. Frost is less likely to occur in localities swept by moisture-laden air which has crossed a considerable body of water. This is more especially the case in the fall of the year, when the temperature of bodies of water is reduced very slowly; and in the South, where the water temperature continues relatively high throughout the year, the influence of the water is especially marked. During the colder months air is not only warmed in crossing considerable bodies of water, but it also absorbs moisture, which, although invisible in the form of water vapor, has the effect of retarding the radiation of heat from the earth. In fact, so pronounced is the influence of water and water vapor that localities which with reference to exposure to west and northwest winds are, as it were, in the lee of large bodies of water are comparatively free from frost visitations. On the keys of the east Florida coast, which are protected on the west by lagoons, rivers, lakes or bays, frost is said to be unknown, and throughout the central and northern sections of the United States, localities which are protected on the west and northwest by bodies of water of considerable size are not only favored, by reason of their position, with conditions which do not promote the formation of frost, but also receive the benefits derived from heavier falls of snow.

Local soil conditions constitute, to a certain extent, a factor in the formation of frost. As a rapid loss of heat is promoted by an active

evaporation of moisture, it is evident that, with other conditions equal, frost is more likely to occur on damp than on dry ground, provided, however, that the ground is not too moist, for in the latter event the amount of moisture evaporated and added to the air would have a tendency to retard the radiation of heat from the earth. And herein lies the distinction, so far as frost formation is concerned, between moist air and moist soil. An excess of moisture in the air, in preventing, to a degree, the radiation of heat, is unfavorable to the formation of frost. As frost is the moisture of the air in immediate contact with the earth condensed at freezing temperature, it follows that the earth, from which the moisture of the air is drawn, must contain more or less water, and it is evident that damaging frost will occur with a limited rather than with a large quantity of moisture arising from the earth and a moderately moist and comparatively still air. Both of these conditions usually obtain following, but not too closely following, the rains of spring and autumn. The character of the soil as regards its capacity for retaining moisture must also be taken into account, more especially during periods of comparatively dry weather. Moist soil, as well as the vegetation which springs from it, is chilled to a lower temperature by the evaporation of moisture, and is therefore more subject to visitations of frost than soil which is dry, or into which water penetrates deeply, leaving the surface dry, or soil which sheds the rain and does not absorb and hold water. It is important to note, however, that very moist soil, or soil which contains a large amount of surface water, is, owing to the quantity of moisture yielded to the air, not so subject to the heavy and damaging frosts which visit plants on moderately damp ground or ground that has a small capacity for moisture.

INFLUENCE OF SOIL AND VEGETATION ON MINIMUM TEMPERATURE.

Prof. W. L. Moore, while engaged in studying frost formation in the cranberry bogs of Wisconsin, in 1891 to 1894, came to the conclusion that for a given area the occurrence of frost depended more upon the character of the surface, its covering, and the degree of heat and moisture to which it had been subjected for several days preceding than to the general temperature and pressure of the air, one field receiving an injurious frost, another a light frost, and still another none at all, while apparently the same weather conditions prevailed at a moderate distance above the ground. Experiments carried on since 1906 by Professor Cox in connection with the protection of cranberries show that in the bogs there may be surface differences of from 5° to 10° in temperature, while at an elevation

of 3 feet these differences disappear. Professor Cox is of opinion that variation in temperature is due largely to differences in temperature of the soil or covering. It is as if heaters of varying power were scattered over the bog, giving off heat to the air immediately above. Investigations carried on at Berlin, Cranmoor, and Mather show that in sections which were carefully weeded and cleaned and were free from moss the temperatures were higher. Progressive cranberry growers find that by cultivating, draining, and sanding, low night temperatures are prevented.

DATES OF EARLY AUTUMN AND LATE SPRING FROSTS.

The following table shows for stations of the Weather Bureau throughout the United States dates of first killing frost in autumn and of last killing frost in spring; also the average dates of first killing frost in autumn and of last killing frost in spring:

Dates of first killing frost in autumn and of last killing frost in spring at Weather Bureau stations throughout the United States.

Station.	Date of earliest recorded killing frost in autumn.	Date of latest recorded killing frost in spring.	Average date of first killing frost in autumn.	Average date of last killing frost in spring.
Eastport, Me.	Sept. 8	June 19	Oct. 12	Apr. 28
Northfield, Vt.	Aug. 27	June 7	Sept. 16	May 13
Portland, Me.	Sept. 11	May 31	Oct. 18	Apr. 14
Boston, Mass.	Sept. 30	May 11	Oct. 22	Apr. 26
Nantucket, Mass.	Oct. 1	Apr. 24	Nov. 5	Apr. 10
Block Island, R. I.	Oct. 30	May 11	Nov. 16	Apr. 12
Narragansett, R. I.	Sept. 21	May 30	Oct. 16	Apr. 23
New Haven, Conn.	Sept. 15	..do....	Oct. 17	Apr. 20
Binghamton, N. Y.	Sept. 16	May 21	Oct. 6	Apr. 27
Albany, N. Y.	Sept. 23	May 30	Oct. 17	Apr. 24
New York, N. Y.	Oct. 5	Apr. 30	Nov. 6	Apr. 10
Harrisburg, Pa.	Oct. 3	Apr. 26	Oct. 24	Do.
Philadelphia, Pa.	..do....	Apr. 29	Oct. 30	Apr. 8
Atlantic City, N. J.	Oct. 1	Apr. 25	Nov. 4	Apr. 11
Baltimore, Md.	Oct. 6	May 3	..do....	Apr. 4
Washington, D. C.	Oct. 2	May 11	Oct. 21	Apr. 7
Lynchburg, Va.	Oct. 4	May 7	Nov. 1	Apr. 14
Norfolk, Va.	Oct. 15	Apr. 26	Nov. 12	Mar. 27
Wytheville, Va.	Sept. 14	May 26	Oct. 7	Apr. 23
Charlotte, N. C.	Oct. 8	Apr. 26	Nov. 4	Apr. 1
Raleigh, N. C.	..do....	May 6	..do....	Apr. 5
Hatteras, N. C.	Nov. 7	Apr. 19	Dec. 11	Feb. 28
Wilmington, N. C.	Oct. 16	May 1	Nov. 15	Mar. 27
Charleston, S. C.	Nov. 9	Apr. 2	Nov. 30	Mar. 1
Columbia, S. C.	Oct. 19	Apr. 17	Nov. 8	Mar. 23
Augusta, Ga.	Oct. 8	..do....	Nov. 9	Mar. 20
Savannah, Ga.	Nov. 1	Apr. 5	Nov. 26	Feb. 27
Jacksonville, Fla.	Nov. 12	Apr. 6	Dec. 6	Feb. 14
Jupiter, Fla.	Nov. 18	Apr. 7	Dec. 29	Do.
Atlanta, Ga.	Oct. 11	Apr. 15	Nov. 7	Mar. 24
Macon, Ga.	Nov. 5	Apr. 18	Nov. 14	Mar. 15
Tampa, Fla.	Nov. 28	Mar. 19	Jan. 9	Feb. 8
Pensacola, Fla.	Nov. 12	Apr. 6	Dec. 5	Feb. 23
Mobile, Ala.	Oct. 31	Mar. 28	Nov. 30	Feb. 24
Montgomery, Ala.	Oct. 21	Apr. 5	Nov. 8	Mar. 11
Meridian, Miss.	Oct. 8	Apr. 10	Nov. 2	Mar. 20
Vicksburg, Miss.	Oct. 19	Apr. 6	Nov. 12	Mar. 6
New Orleans, La.	Nov. 19	Mar. 27	Dec. 15	Jan. 24
Shreveport, La.	Oct. 20	Apr. 2	Nov. 11	Mar. 4
Fort Smith, Ark.	Oct. 15	Apr. 6	Nov. 4	Do.
Little Rock, Ark.	Oct. 22	Apr. 14	Nov. 10	Mar. 20

Dates of first killing frost in autumn and of last killing frost in spring at Weather Bureau stations throughout the United States—Continued.

Station.	Date of earliest recorded killing frost in autumn.	Date of latest recorded killing frost in spring.	Average date of first killing frost in autumn.	Average date of last killing frost in spring.
Palestine, Tex	Oct. 20	May 30	Nov. 13	Mar. 13
Galveston, Tex	Dec. 4	Mar. 1	Dec. 25	Feb. 5
San Antonio, Tex	Nov. 9	Mar. 20	Nov. 30	Feb. 25
Corpus Christi, Tex	Nov. 30	Mar. 19	Dec. 25	Feb. 27
Memphis, Tenn	Oct. 2	Apr. 16	Oct. 28	Mar. 24
Nashville, Tenn	Oct. 8	May 14	Oct. 24	Apr. 2
Chattanooga, Tenn	Sept. 30	...do....	Oct. 26	Do.
Knoxville, Tenn	Oct. 1	Apr. 24	Oct. 27	Apr. 3
Louisville, Ky	Sept. 24	May 14	Oct. 29	Apr. 6
Lexington, Ky	Sept. 30	May 20	Oct. 23	Apr. 18
Evansville, Ind	...do....	Apr. 21	Oct. 30	Apr. 10
Indianapolis, Ind	Sept. 21	May 21	Oct. 19	Apr. 16
Cincinnati, Ohio	Sept. 30	Apr. 24	Oct. 25	Apr. 14
Columbus, Ohio	Sept. 21	May 17	Oct. 16	Apr. 16
Elkins, W. Va	Sept. 28	May 24	Oct. 10	May 18
Parkersburg, W. Va	Sept. 24	May 22	Oct. 17	Apr. 11
Pittsburg, Pa	Sept. 25	May 29	Oct. 19	Apr. 26
Oswego, N. Y	...do....	...do....	...do....	Apr. 27
Rochester, N. Y	Sept. 26	May 30	...do....	May 1
Buffalo, N. Y	Sept. 23	May 29	Oct. 16	Apr. 25
Erie, Pa	Oct. 12	May 17	Oct. 29	Apr. 22
Cleveland, Ohio	Oct. 2	May 22	Oct. 31	Apr. 16
Sandusky, Ohio	Oct. 8	May 17	Oct. 26	Apr. 14
Toledo, Ohio	Sept. 9	May 29	Oct. 15	Apr. 24
Detroit, Mich	Sept. 21	May 31	Oct. 11	Apr. 30
Port Huron, Mich	Sept. 22	June 6	Oct. 9	May 8
Alpena, Mich	Sept. 6	June 9	Sept. 26	May 14
Sault Ste. Marie, Mich	Sept. 5	May 29	Sept. 24	May 16
Marquette, Mich	Aug. 22	June 11	Oct. 2	May 15
Escanaba, Mich	Sept. 9	June 16	Oct. 1	May 14
Green Bay, Wis	Sept. 16	May 30	Oct. 4	May 5
Grand Haven, Mich	Sept. 23	May 28	Oct. 10	Apr. 28
Milwaukee, Wis	Sept. 25	May 29	...do....	Apr. 29
Chicago, Ill	Sept. 18	...do....	Oct. 15	Apr. 18
Duluth, Minn	Sept. 15	June 8	Oct. 5	May 3
Minneapolis, Minn	Sept. 13	May 20	Oct. 8	Apr. 27
St. Paul, Minn	Sept. 20	May 25	Oct. 5	May 6
Madison, Wis	Sept. 29	May 13	Oct. 17	Apr. 21
La Crosse, Wis	Sept. 21	June 1	Oct. 8	May 2
Dubuque, Iowa	Sept. 27	May 21	Oct. 13	Apr. 20
Davenport, Iowa	Sept. 18	May 22	Oct. 14	Apr. 22
Des Moines, Iowa	Sept. 12	...do....	Oct. 8	Apr. 28
Keokuk, Iowa	Sept. 18	May 4	Oct. 15	Apr. 13
Hannibal, Mo	Sept. 30	May 14	...do....	Apr. 14
Springfield, Ill	Sept. 25	May 22	Oct. 16	Apr. 20
St. Louis, Mo	Sept. 30	...do....	Oct. 27	Apr. 2
Cairo, Ill	...do....	Apr. 19	Oct. 28	Mar. 29
Springfield, Mo	...do....	May 19	Oct. 13	Apr. 16
Columbia, Mo	Sept. 28	May 9	Oct. 15	Apr. 14
Kansas City, Mo	Sept. 30	May 4	Oct. 24	Apr. 10
Topeka, Kans	Sept. 28	May 19	Oct. 13	Apr. 8
Wichita, Kans	Sept. 23	May 15	Oct. 19	Apr. 6
Concordia, Kans	Sept. 27	May 19	Oct. 14	Apr. 24
Omaha, Nebr	Sept. 18	...do....	Oct. 12	Apr. 15
Lincoln, Nebr	Sept. 12	May 10	Oct. 9	Apr. 18
Valentine, Nebr	...do....	June 21	Sept. 18	May 9
Sioux City, Iowa	Sept. 13	May 21	Sept. 27	May 1
Huron, S. Dak	Aug. 23	June 8	Sept. 20	May 13
Pierre, S. Dak	Sept. 12	May 19	Sept. 30	Apr. 30
Moorhead, Minn	Aug. 25	June 8	Sept. 22	May 14
Bismarck, N. Dak	Aug. 23	June 7	Sept. 21	May 15
Williston, N. Dak	Aug. 18	June 10	Sept. 14	May 18
Havre, Mont	Aug. 27	June 6	Sept. 13	May 14
Helena, Mont	Sept. 5	June 9	Sept. 25	May 10
Rapid City, S. Dak	Sept. 13	May 21	Sept. 20	May 1
Lander, Wyo	Aug. 23	June 18	Sept. 11	May 19
Salt Lake City, Utah	Sept. 22	...do....	Oct. 18	Apr. 23
Grand Junction, Colo	Sept. 27	May 15	Oct. 21	Apr. 14
Cheyenne, Wyo	Aug. 29	June 11	Sept. 16	May 22
North Platte, Nebr	Sept. 10	May 23	Sept. 28	May 1
Denver, Colo	Sept. 12	June 6	Oct. 5	May 6
Amarillo, Tex	Oct. 16	May 23	Nov. 1	Apr. 16
Pueblo, Colo	Sept. 12	...do....	Oct. 5	Apr. 26
Dodge, Kans	Sept. 23	May 27	Oct. 15	Apr. 17

Dates of first killing frost in autumn and of last killing frost in spring at Weather Bureau stations throughout the United States—Continued.

Station.	Date of earliest recorded killing frost in autumn.	Date of latest recorded killing frost in spring.	Average date of first killing frost in autumn.	Average date of last killing frost in spring.
Oklahoma, Okla	Oct. 7	Apr. 30	Oct. 31	Apr. 2
Fort Worth, Tex	Oct. 22	May 1	Nov. 19	Mar. 18
Abilene, Tex	Oct. 24	Apr. 16	Nov. 15	Mar. 15
El Paso, Tex	Oct. 23	Apr. 22	Nov. 10	Mar. 20
Santa Fe, N. Mex	Sept. 27	May 18	Oct. 19	Apr. 15
Yuma, Ariz	None.	None.	None.	None.
Phoenix, Ariz	Nov. 9	Mar. 31	Dec. 7	Feb. 18
Spokane, Wash	Sept. 7	June 8	Oct. 17	Mar. 23
Walla Walla, Wash	Sept. 28	May 12	Nov. 7	Apr. 4
Seattle, Wash	Oct. 18	May 27	Nov. 22	Mar. 21
Portland, Oreg	Oct. 13	May 9	Nov. 16	Mar. 17
Tatoosh Island, Wash	Nov. 1	Apr. 19	Dec. 15	Mar. 14
Roseburg, Oreg	Sept. 25	May 16	Oct. 30	Apr. 15
Baker City, Oreg	Sept. 4	June 24	Sept. 27	May 25
Winnemucca, Nev	Aug. 22	June 20	Sept. 24	May 15
Eureka, Cal	Nov. 7	May 1	Dec. 8	Apr. 2
Red Bluff, Cal	Nov. 15	Apr. 25	Dec. 6	Feb. 26
Sacramento, Cal	Oct. 28	Apr. 26	Nov. 15	Feb. 16
San Francisco, Cal	Nov. 18	Apr. 20	Dec. 26	Jan. 8
Fresno, Cal	...do....	Apr. 14	Dec. 15	Mar. 4
San Luis Obispo, Cal	Nov. 19	Apr. 8	Dec. 27	Feb. 20
Los Angeles, Cal	None.	...do.....	None.	Apr. 8
San Diego, Cal	None.	None.	None.	None.

PROTECTION FROM FROST.

A discussion of methods of protection from frost calls for a consideration in great detail, not only of the several approved processes of protection and the extent to which they can be applied in connection with the various crops, but also of the value of these processes under the varying conditions of local topography, local climate, and local soil conditions.

It is evident, in the light of the foregoing statements, that fruit and vegetable growers in rolling and hilly country, or when located in the lee, as regards west to northwest winds, of bodies of water, can, to some extent, so place in their earlier and tenderer fruits and crops that they will, in the first instance, avoid the lowlands and valleys, and in the second take advantage of the more moderate and moist air that crosses water surfaces. For further protection the grower must depend upon artificial appliances. These appliances are designed to produce the following effects or results: To prevent a rapid radiation of heat from the earth; to charge the air with moisture; to warm the air; to create artificial drafts, whereby the air is mixed and the cold air is not allowed to settle to the surface of the earth; or to actually cover or roof in plants.

DEVICES FOR PREVENTING RAPID RADIATION OF HEAT.

Devices designed to prevent a rapid radiation of heat from the earth include screens which can be drawn over plants, vineyards, and groves; loose substances with which low plants may be covered; and

smudge fires built to the windward of areas for which protection is desired. These devices, which of a necessity are operative for very limited areas, have been described by Prof. W. H. Hammon and by Prof. A. G. McAdie.

Glass screens.—In greenhouses and hotbeds advantage is taken of the peculiar property of glass which allows the heat rays of the sun to pass through it, and is almost impervious to the dark *heat* rays from the earth and plants. This is one of the most perfect screens possible, since it not only prevents the loss of heat by radiation, but receives and retains the heat from the sun. The expense precludes its adoption except for the protection of valuable plants and flowers.

Screens of other solid materials have been quite extensively used in protecting vineyards and citrus groves where intense cultivation is practiced and where the location of the groves near an excellent market admits of profit even with expensive methods of cultivation.

Cloth screens.—In Italy and portions of France screens made of muslin strung on wires stretched on poles above the tops of trees or vines have been used extensively. These screens are drawn on nights when frosts are probable, and are pushed back during the day. When the season has advanced so far as to preclude further danger, they are taken down and stored. Of course such a plan could be operated only on a very limited scale, and would then be expensive. This plan has been recently successfully tried in the orange groves of southern California.

Lath screens.—During the past few years screens made of laths fastened to ordinary telephone wire (the spaces between them being about the width of the laths) have been extensively used in Florida. These are spread over a frame erected above the trees or plants. The screens serve not only as a fair protection from frost, but also as a shade from the hot sun. When no longer needed, they can be rolled up and stored away for preservation. At first thought it would seem improbable that a screen covering only half the space (the spaces being as wide as the laths) would afford much protection; but when it is considered that laths have considerable thickness it is plain that while only one-half the vertical rays are screened those inclined between the vertical and horizontal are partially intercepted by the edges as well as the faces of the laths. As a matter of fact, about three-fourths of the sky is screened by this means. By placing the laths in north and south directions the direct rays of the morning sun are completely cut off from the orchard, which admits of the temperature rising slowly. This reduces the liability of injury to plants.

Paper cover.—A new form of cover, known as an antifrost cover, has been devised in the San Francisco Weather Bureau office. It is, however, best suited for the protection of small fruit, garden flowers, and vegetables. It is an old and widely known practice to cover garden flowers with newspapers when frost is expected. In the antifrost cover there is used instead of a single cover a double layer of prepared paper with an intervening air space. This prevents almost perfectly the escape of the long heat waves from the ground. Such covering can be spread above the plant an hour or two before sunset, i. e., before the ground has lost much of its heat. If at the same time shallow pans of warm water are placed under the cover, an effective screen and serviceable supply of water are provided. It is also to be noted that we use this cover at a time when the roots are absorbing vigorously and transpiration by the leaves is at a maximum. We therefore prevent any lowering of temperature at the leaf surface and store up in the plant a quantity of heat energy for expenditure slowly through the night hours. The actual temperature of the air is of less importance than the temperature of the leaf or fruit surface. A deposit of moisture is advantageous.

A special use of the antifrost cover in connection with tree fruits is to unroll the covers in the orchard before sunset and to roll them up about 4 o'clock in the morning.

Other methods.—Strawberries and other low plants are frequently protected by covering them with straw or other loose substances.

Frequently young potato plants are saved by plowing a furrow alongside and allowing the dirt to bury them.

Cranberry growers in the marshes of Massachusetts, New Jersey, and Wisconsin flood the marshes when frost is expected. In this case the protection is probably due, for the most part, to the high specific heat of the water, as only portions of this land are submerged. Cultivating, draining, and sanding are now resorted to with such good results that there is practically no need of flooding except in spring and autumn.

DEVICES FOR ADDING HEAT TO THE AIR.

The first successful attempts to prevent injury by frost by the use of heating devices on a large scale occurred in California about 1896. Among a number of protective methods based upon heating, described by Prof. A. G. McAdie, may be mentioned the device of Edward Copely, of Riverside, Cal., in which a wire basket filled with coal and sufficient kindling to insure proper combustion was used. The method met with much favor in the orange groves of California. With from 20 to 40 of these baskets to the acre the temperature under ordinary winter weather conditions can be raised 3 degrees or more.

The first use of oil that we have a record of was by Everett, at Arlington, Cal., and the first use of hot water was by Meacham at Riverside.

A severe frost about the end of December, 1895, caused great damage to the orange crop in the Riverside section, and the following year may be said to have marked the beginning of the frost-fighting campaign. The Riverside Horticultural Club took an active interest in the problem and many experiments were conducted by such men as those above mentioned and Koethen, Reed, Holmes, Hall, Hammon, McAdie, and others. The work has gone on, and there are now on the market many forms of heating devices. A convenient and serviceable frost alarm thermometer and oil pot were devised by the Weather Bureau official at Fresno, Cal., Mr. J. P. Bolton, for use in the vineyards during the spring frosts. There have recently been put upon the market in the apple sections of Colorado and other Rocky Mountain States orchard heaters burning oil, coal, or other fuel.

The various forms of heaters are known by the name of their inventors or are otherwise designated. It is not desirable in a bulletin of this character to advocate the use of any one special form. Indeed the heater that is most satisfactory in one locality and for a given crop may prove less satisfactory under changed conditions.

As showing the efficiency of these heaters, the following report upon a certain coal-burning heater was made by Prof. O. B. Whipple, field horticulturist, Colorado Experiment Station:

I have the following report to make on the coal-burning heater demonstration, held at your place on the evening of November 12, 1908:

The conditions under which the test were held were such as one would experience in fighting frost in the spring. One hundred heaters were well spaced at 29.5 feet,

covering 2 acres of ground. In placing the thermometers, I was careful to see that no pots were closer than 20.5 feet. Waste saturated with one-half crude oil and one-half kerosene with tree prunings were used to start the fires. The fires were started at 7.45, and responded promptly, as the table will show. One man lighted the 100 pots in eight minutes. All pots started without trouble. The pots were refilled, beginning at 10.15, one man completing the job in forty minutes. A few of the pots on a part of the block were again refilled at 12.30, and all burned until the end of the test. In all 2 tons of coal were consumed in the seven hours, making a total of 40 pounds per pot. The coal used was one-half lump and one-half nut and came from the Farmers' mine and Stokes' mine. The temperature readings shown in the table were taken at an elevation of 7 feet from the ground. A thermometer at 12 feet from the ground inside the heated area showed one degree higher temperature.

The following table shows the temperature readings for the full seven hours:

Hour.	Outside temperature.	Inside temperature.	Gain.	Hour.	Outside temperature.	Inside temperature.	Gain.
p. m.	°*F.*	°*F.*	°*F.*	*p. m.*	°*F.*	°*F.*	°*F.*
7.45	30.2	30.2	....	12.00	29.3	36.9	7.6
8.15	31.1	35.6	4.5	*a.m.*			
8.30	28.4	32.9	4.5	12.30	25.7	32.6	69.
9.00	28.4	34.2	5.8	1.00	26.1	32.4	6.3
9.30	28.4	33.8	5.4	1.30	26.6	33.8	7.2
10.00	28.4	34.2	5.8	2.00	28.4	35.6	7.2
10.30	27.5	32.9	5.4	2.30	28.4	34.5	6.1
11.00	27.5	33.8	6.3	3.00	28.4	33.4	5.0
11.30	28.4	36.0	7.6				

The following table is from the report of the committee in the "under actual frost conditions" test held at W. C. Knight's orchard, Grand Junction, Colo., October 28, 1908. The committee consisted of O. B. Whipple, field horticulturist Colorado Experiment Station; W. C. Knight and John M. Harvey, fruitgrowers.

Outside temperature.	Hour.	Inside temperature, with 50 coal heaters with concentrated draft.	Gain.	Inside temperature, with 100 oil heaters, best make.	Gain.	Inside temperature, with 80 coal heaters, open draft on all sides.	Gain.
°*F.*	*p. m.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
35	8.00	35	....	35	....	35	....
35	8.15	38	3	38	3	36	....
33	8.30	39	6	39	6	38	5
32	8.45	40	8	40	8	37	5
34	9.00	40	6	39	5	38	4
34	9.30	40	6	39	5	37	3
34	10.00	40	6	38	4	38	4
32	10.30	36	4	37	5	36½	4½
31	11.00	35	4	36	5	35	4
30	11.30	36½	6½	36	6	34	4
28	12.00	35½	7½	36	6	34	5
	a. m.						
27	12.30	34¼	7¼	35	8	32	5
27	1.00	34½	7½	35	8	32	5
Average gain...............			6	....	5¾	....	4.4

The following account of the use of smudge pots, as they are called, is given by Mr. Richard H. Sullivan, local forecaster, in the Monthly Weather Review for 1910, vol. 38, pp. 412–413:

The inclosed series of observations were taken for the benefit of members of the Sedgwick County Horticultural Society and others in connection with the frost warnings of March 30 and April 5 and tests of smudge pots in the 1-acre orchard of Mr. Albert Kunkel, in Wichita, on March 31 and April 6, and in a selected plat of the orchard of the Thomas Orchard Company, 3 miles west of Wichita, on April 6. The readings for the Kunkel orchard on March 31 and the Thomas orchard on April 6 were made by the writer, 2 minimum and 5 exposed thermometers, 1 anemometer, and 1 commercial thermometer being used.

On Mr. Kunkel's place 79 pots to the acre were used on March 31 and 70 pots to the acre on April 6; his fruit is still unharmed. In the Thomas orchard, 50 pots to the acre, or 500 pots in all, were used among Jonathan and Grimes Golden apple trees. Unfortunately, the temperature in the latter orchard could not be kept above freezing after 4 a. m. on account of lack of fuel oil. The small number of pots to the acre made it necessary to run them at nearly full capacity, and in order to carry the heat through to sunrise the lighting was delayed until 2 a. m. However, the manager does not consider his loss as great as in some orchards in the vicinity.

The figures show that with from 70 to 80 pots to the acre a fruit crop can be saved when the temperature falls to 25°, or even to 22°, if the work is done thoroughly and systematically. These are the first known practical tests of this character that have been made in this vicinity, and the whole proposition rests upon the question of how much expense for such insurance the investment can stand and still render a profit.

Where artificial methods of prevention of damage were not used during the freezes of March 31 and April 6, especially in the lowlands, there was general loss of apricots, peaches, plums, pears, and a very large proportion of apple buds, making the third series of disastrous spring frosts in 4 years. Last year the whole fruit-tree crop was killed by a single freeze during the night of April 30–May 1, warning of which was given the day before.

There is now a general disposition among local horticulturists to adopt the methods of commercial fruit growers elsewhere to prevent damage by frosts and freezes, and the belief is steadily growing that the warnings of this service must be heeded if loss is to be avoided.

Comparative temperature, wind velocity, and weather readings made in connection with test of central-draft smudge pots for prevention of damage by frost or freezing in the orchard of Albert Kunkel.

Half-hourly observations were taken from midnight of March 30–31 to 7.30 a. m., March 31. The arrangement and height of the various instruments are indicated by the letters in the diagram (fig. 3) and the explanation herewith: *A*, Weather Bureau anemometer, 5 feet above ground; *a*, W. B. minimum thermometer No. 6733, 3 feet 8 inches above ground; *b*, W. B. standard thermometer No. 4403, 4 feet 9 inches above ground; *c*, W. B. standard thermometer No. 4788, 4 feet 9 inches above ground; *d*, W. B. standard thermometer No. 4789, 4 feet 9 inches above ground; *e*, W. B. minimum thermometer No. 9436, 3 feet 8 inches above ground; *f*, W. B. standard thermometer No. 3135, 4 feet 9 inches above ground; *g*, W. B. standard thermometer No. 5671, 4 feet 9 inches above ground; *h*, commercial thermometer, 1 foot above ground; *i*, residence; *j*, greenhouse; *k*, barn.

The smudge pots, 79 in number, were lighted between 5.30 and 5.45 a. m., March 31, and extinguished at 7.30 a. m. The temperatures at 6 a. m. in the accompanying table show the effectiveness of such a method during frosty periods. Fuel oil, costing 4 cents per gallon, was used.

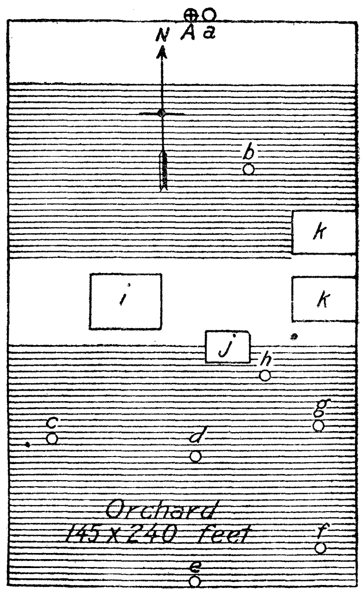

Fig. 3.—Diagram of Kunkel orchard, Wichita, Kans. Shaded areas show limits of smudge pots.

Winds—Northwesterly to 2.30 a. m.; northerly to 6.30 a. m.; northeasterly to 7.30 a. m.

TABLE 1.—*Temperature, weather, and wind velocity, March 31, 1910.*

[Letters in heading indicate position of thermometers.]

Time.	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	Weather.	*A*
	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*		*Miles*
12.00 midnight	39.0	40.5	41.0	41.0	39.0	41.0	40.5	39.0	Clear.	0.2
12.30 a. m	38.5	40.0	39.5	39.5	38.5	39.5	39.5	38.0	Clear.	0.2
1.00 a. m	36.5	38.5	38.0	38.0	37.0	38.5	38.5	37.0	Clear.	0.2
1.30 a. m	35.5	37.5	37.0	37.0	36.0	38.0	37.5	36.0	Clear.	0.2
2.00 a. m	35.0	37.0	37.0	36.0	35.5	36.0	36.0	34.5	Clear.	0.3
2.30 a. m	34.0	36.0	35.5	35.5	34.0	35.5	35.5	34.0	Clear.	0.3
3.00 a. m	35.5	37.0	37.5	37.0	36.0	37.5	37.0	35.0	Clear.	0.4
3.30 a. m	36.0	37.0	39.0	39.0	37.0	38.5	38.0	36.0	Clear.	0.5
4.00 a. m	36.5	37.0	36.5	36.0	35.5	37.0	37.0	36.0	Clear.	0.3
4.30 a. m	35.5	36.5	36.0	36.0	35.0	36.5	36.0	35.0	Clear.	0.3
5.00 a. m	33.0	34.0	33.5	33.0	33.0	34.0	33.0	31.0	Clear.	0.2
5.30 a. m	*a*31.0	32.5	32.5	32.0	31.5	33.0	33.0	30.0	Clear.	0.2
6.00 a. m	31.0	44.0	40.5	38.0	34.0	38.0	38.0	36.0	Clear.	0.3
6.30 a. m	33.0	39.0	40.0	38.5	34.5	37.5	38.0	38.0	Clear.	0.4
7.0 a. m	35.5	38.0	38.0	37.5	35.5	38.0	39.0	38.0	Clear.	0.5
7.30 a. m	40.0	40.5	41.0	41.0	40.0	40.5	40.5	40.0	Clear.	0.5

a Lowest temperatures recorded, 30.5° between 5.00 and 5.30 a. m.

79 smudge pots lighted, beginning at 5.30 a. m. and ending at 5.45 a. m.

Second test made by Mr. Albert Kunkel. Number of pots lighted, 70.

TABLE 2.—*Temperature and weather table, April 6, 1910.*

[Letters in heading indicate location of thermometers as shown on diagram of March 31, 1910.]

Time.	a	b	e	Weather.
	°F.	°F.	°F.	
3.00 a. m.	30	32	......	Clear.
3.30 a. m.	28	31	......	Clear.
4.00 a. m.	27	34	......	Clear.
4.30 a. m.	26	35	......	Clear.
5.00 a. m.	26	36	......	Clear.
5.30 a. m.	27	36	37	Clear.
6.00 a. m.	28	38	38	Clear.
6.30 a. m.	28	35	38	Clear.
7.00 a. m.	30	38	38	Clear.

70 smudge pots lighted, beginning at 3.30 a. m.

Comparative temperature, wind velocity, and weather readings made in connection with test of central-draft smudge pots for prevention of damage by frost or freezing in the orchard of the Thomas Orchard Company, 3 miles west of Wichita.

The smudged portion of the orchard was a selected 10-acre plat containing Jonathan and Grimes Golden apples; the pots were arranged 50 to the acre, or 500 in all. The instruments were placed at a height of 6 feet, except 1 commercial thermometer, which was located 1 foot above the ground near the center. The thermometers are

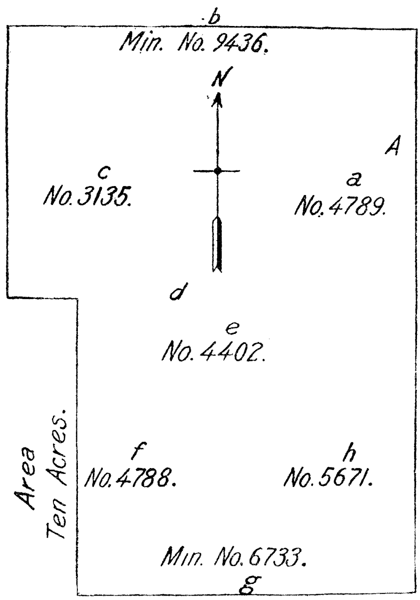

FIG. 4.—Diagram of plat of Thomas Orchard Company, Wichita, Kans.

arranged in the table in the order of reading. The pots were charged with 3 quarts of fuel oil, and lighting was delayed until 2 a. m. on account of lack of oil. The 500 pots were lighted between 2 and 2.35 a. m., and insufficient oil to hold the fires at reasonable capacity resulted in inability to keep temperature above freezing after 4 a. m., and by daylight practically all of the oil had been consumed.

Winds—Northwesterly to 4.30 a. m.; westerly after 4.30 a. m.

The letters in the diagram (fig. 4) of this plat indicate corresponding instruments in Table 3; numbers, United States Weather Bureau thermometers; *d*, commercial thermometer; *A*, anemometer.

TABLE 3.—*Temperature, weather, and wind velocity.*

[Letters in heading indicate position of thermometers.]

Time.	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	Weather.	*A*
	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*		*Miles.*
12.00 midnight	31.5	31.5	32.0	31.5	32.0	31.0	31.0	31.0	Clear.	0.2
1.00 a. m.	31.0	31.0	31.0	32.0	31.5	31.0	31.0	30.5	Clear.	0.2
2.00 a. m.	30.0	[a]30.0	30.0	30.0	30.0	29.5	31.5	29.5	Clear.	0.1
3.00 a. m.	33.5	33.5	33.5	35.0	34.0	33.5	34.5	33.0	Clear.	0.1
4.00 a. m.	32.5	32.0	32.5	32.0	32.5	32.5	33.5	32.0	Clear.	0.1
5.00 a. m.	31.0	31.5	31.0	31.5	30.5	29.0	30.0	30.0	Clear.	0.2
6.00 a. m.	31.0	30.0	30.0	30.0	30.0	29.0	29.0	28.5	Clear.	0.1

[a] Lowest temperature recorded, 29.0° between 1.00 and 2.00 a. m.

500 smudge pots lighted, beginning at 2.00 a. m. and ending at 6.35 a. m.

Additional report, April 30, 1910.

Further trials in the Thomas orchard on April 19, 24–25, fully confirm the efficacy of the firing methods above explained in detail. The wind-velocity records show, as was to be expected, that the most damaging temperatures occur after the wind has died down. Artificial preventive methods can be used effectively despite the oft-repeated arguments that it is too windy in Kansas.

In a paper read before the California Fruit Growers' convention at Watsonville, December, 1909, the district forecaster discusses in some detail the various forms of heating devices, such as open fires, smudge fires, coal baskets, oil pots, orchard heaters, etc., as used in the protection of citrus fruits in that State.

Many small fires are found to be much more effective than one or two large fires. The great mass of experiments made in California orchards show that direct heating of the air by open fires has not been sufficient to prevent injury at times of very low temperatures. A large amount of the heat thus produced is wasted; the efficiency of the method is low. This is illustrated by the following experience of a gentleman who is a close observer, an earnest student of the problem of frost-protection, and one in whom I have the greatest confidence. During the night of December 20–21, 1908, on a certain California ranch, the temperature for fourteen hours ranged between 19° and 24° F. For thirty-six hours the temperature did not rise above 28°. During this night the gentleman referred to burned 15 cords of wood and about 40 tons of wet hay in his efforts to protect his orchard. The relative humidity was low, there was little movement of the air, and he reports that "the smoke rose as straight as a pine tree." At the intersection of two roads in the orchard a large fire was maintained, and 30 feet distant the temperature in an olive tree was observed. Another fire was burning within 20 feet of this tree on a second side, and on yet a third side was a third fire maintained within 25 feet of the same tree. The temperature at the tree, however, remained at about 20° F. from 3 to 8 a. m. of December 21. This was the coldest weather in this locality since 1888. It is evident that in this case a large amount of heat escaped without producing the desired warming effect, i. e., was lost, wasted. It is, of course, well known that the rate of conduction of heat through air is low.

DEVICES FOR ADDING MOISTURE TO THE AIR.

Smudge fires made of damp material have been more successfully used for the purpose of affording protection from frost than those made of tar, crude petroleum, and other dry materials, for the reason

that in addition to creating a dense smoke they add to the atmosphere a considerable amount of evaporated water, which, though invisible, serves to retard the radiation of heat. When any considerable amount of water is thus converted into vapor and is distributed in the air which covers the area to be protected, a portion of it is likely to be condensed by the surrounding cooler air and appear in the form of mist, which acts as an agent to prevent the escape of heat from the earth; and the act of condensation sets free in the air some of the heat that has been expended in the process of evaporating the water contained in the smudge-fire materials. Thus the process is well ordered throughout. In the first place, an undue quantity of heat, whereby undesirable drafts would be created, is not communicated to the air by the fires, and the final result is that in reliberating, by condensation, the water in the air the particles of moisture remain suspended in the air, and some of the heat of the fires is returned to the air in a form which, to a certain degree, warms it without causing currents which would be calculated to disturb the smoke cloud, or pall, and the moist air which overlies the ground and uoon whose presence the safety of the plants from frost depends.

Portable smudge fires.—A number of excellent devices have been tried, in which the fires were built upon some vehicle by which they could be moved about the orchard. The advantages of this plan are several.

First. The fire can be moved to the section where most needed, which is generally along the windward side of the orchard.

Second. The loss of heat by an upward draft is almost entirely prevented, since the fire does not remain in one position long enough to establish such a draft. On this account much larger and, consequently, fewer fires, with equal efficiency, are possible.

Third. There is a much more uniform distribution of heat and smoke throughout the orchard.

Aside from the smudge fires, other devices have been adopted to charge the air directly with moisture, some of which are constructed on a plan too elaborate and expensive for general use.

The first operation involved is the evaporation of water in large quantities, either by means of evaporating pans or by the use of boilers with connecting pipes whereby steam can be generated, conducted, and discharged into the air in different parts of a field or orchard.

Spraying and sprinkling plants in times of threatened frost has also been attended with some degree of success. At the Everest ranch, at Riverside, Cal., sprinklers are placed at the top of 50-foot masts, which fill the air with a very fine spray. In nearly every instance the protection against frost by this method has been sufficient.

Sprinkling gardens before sunrise on frosty mornings has proved of decided value.

Secondly, irrigation, which of necessity can be used only to a very limited extent and in certain favored localities, has been found to afford very complete protection from frost in fields, orchards, and vineyards which are equipped with irrigation ditches, and in the cranberry districts of Wisconsin and Cape Cod perfect protection from damage by frost is secured by flooding the cranberry marshes the day before heavy frost occurs in those sections.

In no case should water be allowed to stand in orchards, vineyards, or gardens during the early growing period while danger from frost is possible, for the reason that water unduly promotes the growth of young plants and thereby renders them more susceptible to damage by frost and cold than are the plants whose growth is retarded.

GENERAL OBSERVATIONS AND PRACTICAL RESULTS.

The general campaign of frost fighting, as thus far laid out, covers three main lines:

(1) Accurate advance information of the occurrence of frost.

(2) Applying preventive measures during critical hours.

(3) Preventing sudden warming of chilled fruit, or a too rapid thawing out.

Under the first of these heads great progress has been made in the past five years. Throughout the various fruit sections of the United States, Weather Bureau officials recognize the value of special study of types of frost maps. The work first undertaken in California on a large scale and for a distinct purpose is now an important feature of the forecaster's work at a large number of places. Frosts are found to occur as a consequence of certain movements of low and high pressure areas and the displacement of the lower air incident to the pressure changes. Frost is a matter of air drainage, both on a large scale and on a small scale. In other words, frosts are successfully forecast because we understand the general movements of the lower air and in particular certain local circulations.

The forecaster anticipates a condition in which the lower air strata are quiet, dust free, and very dry. Under such condition there is rapid radiation and loss of heat from plant and ground and a sharp fall in temperature. While the forecaster gives the general conditions favorable for frost, it must be clearly understood that each individual orchardist must study his own problem of air movement in his own locality. These local circulations should be studied in connection with the daily weather map. It is also advisable to have certain instrumental records, such as are given by the thermograph and hygrograph.

Under the second head we have discussed the physical processes operative in the formation of frost and mentioned the various devices, such as smudging outfits, coal baskets, oil pots, orchard heaters, antifrost covers, etc. Opinions will differ as to the relative efficiency of various devices, and some are undoubtedly more serviceable for certain localities than others.

There are three general principles used in frost-protection devices:

(1) Adding heat.

(2) Saving heat.

(3) Mixing or stirring the air.

Under the third head, methods based upon mixing or stirring the air, no special devices that are available and practicable are known. When nature mixes the air—i. e., on windy nights—frost does not occur. It is now known to meteorologists that layers of air of different temperature may lie close to one another without mixing. On nearly every frosty night there is a difference of 6, 8, or 10 degrees in temperature between the ground and the air 10 feet above, the warmer layers being above. Where air is well mixed and there is good ventilation, we seldom find frost.

WORK IN FLORIDA.

Devices used in Florida for the protection of fruit, vegetables, and berries from frost and light freezes conform in character to those tested in the California experiments, in which fires were found to be the most effective means of protection, and appliances for adding moisture to the air were successful only to a slight degree.

As artificial appliances are totally inadequate to add to the atmosphere any very appreciable amount of moisture, it is evident that methods which may have been found ineffective in the dry climate of California would possess value in localities where their office is confined to adding moisture to an already moist atmosphere. The Gulf and South Atlantic Coast States, and in fact the country generally from the Mississippi Valley to the Atlantic seaboard, possess a moist atmosphere, and the fruits and tender vegetables of these districts can, therefore, be the more readily protected from frost by devices which add moisture to the air. As a means of adding moisture to the air, irrigation should be more effective than in California; and in localities where this method can be used protection will be assured except against hard freezes.

Owing to the comparatively inexpensive character of the materials used in damp smudge fires, they seem the best adapted for common use in groves and gardens. Berries and other low plants can be protected with but little expense by coverings of straw and other light materials. In Florida pine needles are successfully used to pro-

tect strawberries. Devices for actually heating the free and open air are expensive, and their value is dependent solely upon a comparatively still air and small, numerous, and well-distributed fires.

In Florida many experiments have been made with a view to adopting devices which will protect citrus trees and fruits from injury during the periods of severe cold which at times visit that section. The fact that these periods of cold are infrequent does not relieve the grower from the necessity of providing for their occurrence. Effective measures of protection necessarily vary with the conditions that confront the grower. Protection can be made effective by tents, coverings of cloth, sheds, and one-half and one-third lath shelters and their modifications, that retain heat from open wood fires and sheet-iron stoves. The expense of these methods is obviously too great to make their employment, except for choice varieties of fruit, commercially profitable.

In this State protection of citrus trees and fruit in the open field is usually afforded by what is known as "firing." This method is effective, except in the presence of severe freezes, provided rain or strong winds do not accompany the cold. Heavy rain will, of course, extinguish the fires, and strong winds will not permit a necessary accumulation of warm air about the trees. When no rain is falling and the wind is light, fires must be built on the windward side of the trees, so that the heat will be carried through the trees, and the number of the fires must be regulated by the degree of cold. In this form of protection the grower must lay in and place his materials for "firing" before the winter season sets in, and must, during the season, be on guard to utilize the materials (usually wood) that he has accumulated. When local indications point to dangerously low temperatures, or when warnings have been received from the Weather Bureau, he should watch his thermometers, exposed in the groves, and be prepared to "fire" with a rush when the mercury sinks to the danger point, 28° F., with a downward tendency. There is no time on the eve of a freeze to collect firing materials, and the grower must not desert his grove for bed or board so long as danger by cold continues. He will have his hands full keeping his fires going, even if he has sufficient material for that purpose. Material should be available for at least three nights. Cold spells seldom last longer. The danger increases with the length of the cold spell. Trees and fruit become chilled and the last night of a cold spell is likely to be the one that does the damage. The freeze of December 23–27, 1906, lasted five nights, and in some sections the last night produced the lowest temperatures of the period. In some localities growers had exhausted their supply of firing material and, as a consequence, suffered a loss of fruit and young trees.

In cases of severe cold, fruit can not be saved, and trees can be preserved only by banking up the trunks by sand or soil. Small trees can be buried, and older trees can at least be protected above the parts where they have been budded.

The damage that will result from a given degree of cold varies with the condition and size of the tree. Well-grown trees in a dormant condition will stand without serious injury, except to foliage, a temperature of 18° to 20°, provided it is not too long continued. When the sap is flowing these temperatures are likely to kill growing trees, and are apt to cut small, unprotected trees to the ground. Well-grown trees in a dormant condition will stand without injury a temperature of 26° of continued cold, and can for several hours stand temperatures of 22° to 24°. When the sap is flowing these temperatures continued for several hours will be more or less injurious. Cold that will freeze fruit will injure small trees. In the freeze of December 23–27, 1906, temperatures in parts of the orange belt fell to 20°, and even to 18° and below, on one and in some cases two nights without injury to large trees, except to foliage, and with a surprisingly small loss of fruit and small trees. This freeze had been preceded by about two months of rainless weather, and found the trees in a dormant condition. The destructive freezes of preceding years usually followed periods of wet weather that promoted a flow of sap.

WORK IN MISSOURI.

In the Monthly Weather Review for May, 1910, Professor Howard, secretary of the Missouri State Board of Horticulture, expresses the following views relative to critical temperatures and the necessity of definite and detailed advance information in connection with frosts:

The horticulturists at the University of Missouri have closely determined the temperatures representing the danger point to fruit for the different stages in its development, as shown by the following brief summary of Circular No. 13, Missouri Experiment Station, 1909:

"Fully dormant peach buds can stand 8° or 9° below zero (F.). When they are appreciably swollen, zero is the danger point. When the buds are showing pink, they can stand 15° above zero. When the buds are almost open, 25° is the point of danger. When the petals are beginning to fall, 28° above zero is cold enough to cause uneasiness. When the petals are off, they can stand 30° above zero. When the 'shucks' (calyx tubes) are beginning to fall off, 32° above zero is the danger point."

It is estimated that the April, 1910, freeze caused a loss to the people of Missouri of $2,500,000, and it would mean thousands of dollars to the fruit growers in carrying out protective measures in the future to know just when to start the heaters in the orchards. It has been demonstrated that it is not a difficult matter, if one is prepared for it, and knows how to start the work, to raise the temperature in an orchard 5° to 6°, sufficient during almost any cold night in the spring to save many an orchard from injury. The question asked so often is, "When shall we start the heaters?" To start them too soon is expensive, but to start them too late would be more expen-

sive in the end. In this matter of advice the Weather Bureau must shoulder the burden, and it must take up the task with an earnestness that should prove successful. The forecaster must be thoroughly familiar, not only with the geographical location and topographical conditions of the section for which forecasts are made, but he must keep himself fully informed as to the progress of the fruit crop in its different stages of advancement. The state forecast issued by the district forecaster is all that is necessary for the public in general, but where specific information is desired it is not satisfactory. It will not suffice to simply send a weather message to a fruit locality in time of danger from low temperature, reading "Fair to-night and colder, with frost;" but the message must say *how cold* it is expected to be; for instance, something like the following: "Fair and colder to-night, with frost; temperature about 36°; no danger to fruit." And again, "Fair and colder to-night, with freezing temperature; 28° or lower by morning; start heaters after midnight."

While specifying the exact degree of cold expected may not be practicable for the district forecaster, owing to the extent of territory forecast for, and the limited time in which he has to make the forecast, it is being done, and can doubtless be brought to a high degree of accuracy, by the local forecasters.

DISTRIBUTION OF FORECASTS IN CALIFORNIA.

The system of frost warnings has reached a high degree of efficiency in California. The district forecaster sends telegrams each night to important fruit centers during the frost period, indicating the type of frost, whether light, heavy, or killing, the general weather conditions, and advice as to whether fire will be necessary.

To illustrate the way in which the information is distributed from the larger centers, the following statement is furnished by Mr. A. B. Wollaber, local forecaster at Los Angeles:

In California, where the changes in weather conditions can be only forecast for a short time in advance and where changes from one extreme to the opposite are often sudden, it has been found necessary to adopt a system whereby the local office can keep in touch at all times with the citrus industry. Here we find that the best means for accomplishing this purpose is the telephone, and in addition to the free distribution of our warnings by the long-distance companies operating in this section, we have an arrangement whereby we can reach the entire fruit belt within half an hour and disseminate our warnings through the medium of the fruit exchanges. The Weather Bureau pays for this service and therefore is in a position to demand and to receive prompt service. To accomplish this we have prepared a list of the exchanges in the fruit belt to which we send our warnings, and this list is on file with the chief operators of the long-distance companies. When we desire to send a warning we call for long-distance chief operator and give the message, which is immediately sent out. This system is used only in extreme cases, as when the regular maps and cards have been sent without a frost warning. That could occur in this manner: When a storm which gives indication of clouds or rain during the period covered by the morning forecast passes eastward more rapidly than was anticipated, causing a rapid clearing, and when later information from the district forecaster shows the probability of more severe conditions than anticipated on the morning reports.

Now, it happens in this section that not all ranches need protection at all times. The managers of the several fruit exchanges are personally familiar with conditions in their respective sections and are considered to be best qualified to disseminate this important information.

Special frost-warning cards are mailed to all post-offices, fruit exchanges, and railroad depots before the frost period begins. There has grown up a personal relationship between the growers and the local office, and through this much good has been accomplished.

MISCELLANEOUS.

A TWO YEARS' STUDY OF SPRING FROSTS AT WILLIAMSTOWN, MASS.

A valuable paper by Prof. W. I. Milham on the above subject was published in the Monthly Weather Review for August, 1908. The special purpose of the investigation was the critical study of the spring frosts, first, to test the prevalent belief that the probable minimum temperature could be computed from the maximum and dew-point, or from the reading of the wet-bulb thermometer of the afternoon before the frost; second, to study the variation in the severity of frost at different places within a small area; and, third, to study the variation in the severity of frost with varying distances above the ground. Professor Milham came to the following conclusions:

(1) The cool nights of spring when a frost might be expected are very dry, and the dew-point lies so low that it plays practically no part in determining the minimum temperature.

(2) The amount of the drop from the maximum to the following minimum is very far from a constant, even if the characteristics of these nights seem very nearly the same. In each case in estimating the probable drop one must take into account the probable amount of cloud, the probable wind velocity, the possibility of a change in wind direction, and possibly other things.

Milham holds that two processes operate to produce the cooling, first, the importation of cooler air, and, second, the radiation of heat from the ground and the cooling of the air next to it by conduction. It might seem that the cool nights during which frosts seem probable could be divided into two groups, depending upon whether the importation of cold air or radiation from the ground was playing the larger part in producing the cooling. It is found, however, that both processes are nearly always operative. It may not be out of place at this point to call attention to the fact that the heat which has been absorbed by the ground is re-emitted as radiation of long wave lengths, from 4 μ to 20 μ.

Milham calls attention to the fact that the temperature of vegetation in the open, near the ground, in the coldest part of the tract may be 11° lower than the estimated minimum in a given shelter.

An interesting paper upon temperature variations near the surface of the soil during the formation of frost, by Mr. Dewey A. Seeley, local forecaster, can be found in the Monthly Weather Review for August, 1908. He is of the opinion that a considerable amount of

the heat given off, during the condensation of vapor as frost and dew, is retained in saturated air near the ground level and also by the foliage of the plants themselves. The influence of a surface covering of vegetation on the temperature of the soil was marked. It was found that the soil beneath the grass was warmer both at night and during the day than the naked soil; but the temperature of the air above the grass was lower in both cases than over bare ground.

The dew-point as recorded at 7 p. m. and the minimum temperature registered the following morning for sixty days were tabulated and the differences computed. From these it appears that on the average the minimum temperature went 2.9° below the 7 p. m. dew-point. In but three cases did the temperature fall more than 10° below the dew-point recorded at 7 p. m. The thermograph traces made during clear weather with light wind show that the temperature fall goes on much more rapidly during the first part of the night, before the dew-point is reached.

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